CLAIMS

1. A piezoelectric element comprising a first electrode film, a layered piezoelectric film including a first thin piezoelectric film provided on the first electrode film and a second thin piezoelectric film provided on the first thin piezoelectric film and a second electrode film provided on the layered piezoelectric film, wherein

the layered piezoelectric film is made of rhombohedral or tetragonal perovskite oxide having preferred orientation along the (111) plane,

the first and second thin piezoelectric films are aggregates of columnar grains, respectively, which are continuously linked to each other,

the columnar grains of the second thin piezoelectric film have a larger average cross-sectional diameter than the columnar grains of the first thin piezoelectric film and

the ratio of the thickness of the layered piezoelectric film to the average cross-sectional diameter of the columnar grains of the second thin piezoelectric film is 20 to 60 inclusive.

2. A piezoelectric element according to claim 1, wherein

the columnar grains of the first thin piezoelectric film have an average cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm inclusive.

3. A piezoelectric element according to claim 1, wherein

the columnar grains of the second thin piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm inclusive.

4. A piezoelectric element according to claim 1, wherein

the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,

the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to 80 % inclusive and

the degree of (111) crystal orientation of the second thin piezoelectric film is 95 % to 100 % inclusive.

5. A piezoelectric element according to claim 1, wherein

the chemical composition ratio of the layered piezoelectric film is represented as [Pb]:[Zr]:[Ti] = (1+a):b:(1-b),

the first and second thin piezoelectric films have the same value b of 0.40 to 0.60 inclusive,

the first thin piezoelectric film has a larger Pb content than the second thin piezoelectric film,

the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and

the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

6. A piezoelectric element according to claim 1, wherein

the layered piezoelectric film is made of lead zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

7. A piezoelectric element according to claim 1, wherein

the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy containing the noble metal and is an aggregate of columnar grains having an average cross-sectional diameter of 20 nm to 30 nm inclusive.

8. An inkjet head comprising: a piezoelectric element according to claim 1 including a first electrode film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order; a diaphragm layer disposed on the second electrode film side surface of the piezoelectric element; and a pressure chamber member including a pressure chamber for containing ink which is bonded to the surface of the diaphragm layer opposite to the second electrode film, such that the ink in the pressure chamber is discharged out by displacing the diaphragm layer in the thickness direction by the piezoelectric effect of the layered piezoelectric film.

9. An inkjet head comprising: a piezoelectric element according to claim 1 including a first electrode film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order; a diaphragm layer disposed on the first electrode film side surface of the piezoelectric element; and a pressure chamber member including a pressure chamber for containing ink which is bonded to the surface of the diaphragm layer opposite to the first electrode film, such that the ink in the pressure chamber is discharged out by displacing the diaphragm layer in the thickness direction by the piezoelectric effect of the layered piezoelectric film.

10. An inkjet recording device comprising

an inkjet head according to claim 8 and

a relative movement mechanism for relatively moving the inkjet head and a recording medium, wherein

recording is carried out by discharging the ink in the pressure chamber from a nozzle hole communicating with the pressure chamber onto the recording medium while the inkjet head and the recording medium are relatively moved by the relative movement

mechanism.

11. An inkjet recording device comprising

an inkjet head according to claim 9 and

a relative movement mechanism for relatively moving the inkjet head and a recording medium, wherein

recording is carried out by discharging the ink in the pressure chamber from a nozzle hole communicating with the pressure chamber onto the recording medium while the inkjet head and the recording medium are relatively moved by the relative movement mechanism.

12. An angular velocity sensor comprising: a substrate including a stationary part and at least a pair of vibrating parts extending in a certain direction from the stationary part; a piezoelectric element according to claim 1 including a first electrode film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order at least on the vibrating parts of the substrate; and the second electrode film on each of the vibrating parts is patterned into at least one drive electrode for vibrating the vibrating parts in the width direction and at least one detection electrode for detecting deformation of the vibrating parts in the thickness direction.

13. An angular velocity sensor according to claim 12, wherein

the columnar grains of the first thin piezoelectric film have an average cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm inclusive.

14. An angular velocity sensor according to claim 12, wherein

the columnar grains of the second thin piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm inclusive.

15. An angular velocity sensor according to claim 12, wherein

the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,

the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to 80 % inclusive and

the degree of (111) crystal orientation of the second thin piezoelectric film is 95 % to 100 % inclusive.

16. An angular velocity sensor according to claim 12, wherein

the chemical composition ratio of the layered piezoelectric film is represented as [Pb]:[Zr]:[Ti] = (1+a):b:(1-b),

the first and second thin piezoelectric films have the same value b of 0.40 to 0.60 inclusive,

the first thin piezoelectric film has a larger Pb content than the second thin piezoelectric film,

the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and

the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

17. An angular velocity sensor according to claim 12, wherein

the layered piezoelectric film is made of lead zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

18. An angular velocity sensor according to claim 12, wherein

the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy containing the noble metal and is an aggregate of columnar grains having an average cross-sectional diameter of 20 nm to 30 nm inclusive.

19. An angular velocity sensor according to claim 12, wherein

the substrate is made of Si.

20. A method for manufacturing a piezoelectric element comprising the steps of:

forming a first electrode film on a substrate by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the first electrode film by sputtering to provide a layered piezoelectric film; and

forming a second electrode film on the layered piezoelectric film, wherein

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane.

21. A method for manufacturing an inkjet head comprising the steps of:

forming a first electrode film on a substrate by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the first electrode film by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film;

forming a diaphragm layer on the second electrode film;

bonding a pressure chamber member for providing a pressure chamber to the surface of the diaphragm layer opposite to the second electrode film; and

removing the substrate after the bonding step, wherein

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane.

22. A method for manufacturing an inkjet head comprising the steps of:

forming a diaphragm layer on a pressure chamber substrate for providing a pressure chamber;

forming a first electrode film on the diaphragm layer by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the first electrode film by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film; and

forming a pressure chamber in the pressure chamber substrate; wherein

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane.

23. A method for manufacturing an angular velocity sensor comprising the steps of:

forming a first electrode film on a substrate by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the first electrode film by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film;

patterning the second electrode film into a drive electrode and a detection electrode;

patterning the layered piezoelectric film and the first electrode film; and

patterning the substrate to provide a stationary part and a vibrating part, wherein

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane.

24. A piezoelectric element according to claim 1 further comprising an orientation control film disposed between the first electrode film and the first thin piezoelectric film, wherein

the orientation control film is made of cubic or tetragonal perovskite oxide having preferred orientation along the (111) plane.

25. A piezoelectric element according to claim 24, wherein

the columnar grains of the first thin piezoelectric film have an average cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm inclusive.

26. A piezoelectric element according to claim 24, wherein

the columnar grains of the second piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm inclusive.

27. A piezoelectric element according to claim 24, wherein

the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,

the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to 80 % inclusive and

the degree of (111) crystal orientation of the second thin piezoelectric film is 95 % to 100 % inclusive.

28. A piezoelectric element according to claim 24, wherein

the chemical composition ratio of the layered piezoelectric film is represented as [Pb]:[Zr]:[Ti] = (1+a):b:(1-b),

the first and second thin piezoelectric films have the same value b of 0.40 to 0.60 inclusive,

the first thin piezoelectric film has a larger Pb content than the second thin piezoelectric film,

the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and

the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

29. A piezoelectric element according to claim 24, wherein

the orientation control film is made of oxide based on perovskite lead lanthanum zirconate titanate and

the degree of (111) crystal orientation of the orientation control film is 50 % or more.

30. A piezoelectric element according to claim 24, wherein

the chemical composition ratio of the orientation control film is represented as [Pb]:[La]:[Zr]:[Ti] = x × (1-z):z:y:(1-y),

the value x is 1.0 to 1.20 inclusive,

the value y is 0 to 0.20 inclusive and

the value z is more than 0 and not more than 0.30.

31. A piezoelectric element according to claim 24, wherein

the orientation control film is made of lead lanthanum zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

32. A piezoelectric element according to claim 24, wherein

the layered piezoelectric film is made of lead zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

33. A piezoelectric element according to claim 24, wherein

the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy containing the noble metal and is an aggregate of columnar grains having an average cross-sectional diameter of 20 nm to 30 nm inclusive.

34. An inkjet head comprising: a piezoelectric element according to claim 24 including a first electrode film, an orientation control film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order; a diaphragm layer disposed on the second electrode film side surface of the piezoelectric element; and a pressure chamber member including a pressure chamber for containing ink which is bonded to the surface of the diaphragm layer opposite to the second electrode film, such that the ink in the pressure chamber is discharged out by displacing the diaphragm layer in the thickness direction by the piezoelectric effect of the layered piezoelectric film.

35. An inkjet head comprising: a piezoelectric element according to claim 24 including a first electrode film, an orientation control film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order; a diaphragm layer disposed on the first electrode film side surface of the piezoelectric element; and a pressure chamber member including a pressure chamber for containing ink which is bonded to the surface of the diaphragm layer

opposite to the first electrode film, such that the ink in the pressure chamber is discharged out by displacing the diaphragm layer in the thickness direction by the piezoelectric effect of the layered piezoelectric film.

36. An inkjet recording device comprising

an inkjet head according to claim 34 and

a relative movement mechanism for relatively moving the inkjet head and a recording medium, wherein

recording is carried out by discharging the ink in the pressure chamber from a nozzle hole communicating with the pressure chamber onto the recording medium while the inkjet head and the recording medium are relatively moved by the relative movement mechanism.

37. An inkjet recording device comprising

an inkjet head according to claim 35 and

a relative movement mechanism for relatively moving the inkjet head and a recording medium, wherein

recording is carried out by discharging the ink in the pressure chamber from a nozzle hole communicating with the pressure chamber onto the recording medium while the inkjet head and the recording medium are relatively moved by the relative movement mechanism.

38. An angular velocity sensor comprising: a substrate including a stationary part and at least a pair of vibrating parts extending in a certain direction from the stationary part; a piezoelectric element according to claim 24 including a first electrode film, an orientation control film, a layered piezoelectric film including a first thin piezoelectric film and a second thin piezoelectric film and a second electrode film stacked in this order at

least on the vibrating parts of the substrate; and the second electrode film on each of the vibrating parts is patterned into at least one drive electrode for vibrating the vibrating parts in the width direction and at least one detection electrode for detecting deformation of the vibrating parts in the thickness direction.

39. An angular velocity sensor according to claim 38, wherein

the columnar grains of the first thin piezoelectric film have an average cross-sectional diameter of 40 nm to 70 nm inclusive and a length of 5 nm to 100 nm inclusive.

40. An angular velocity sensor according to claim 38, wherein

the columnar grains of the second piezoelectric film have an average cross-sectional diameter of 60 nm to 200 nm inclusive and a length of 2500 nm to 5000 nm inclusive.

41. An angular velocity sensor according to claim 38, wherein

the first and second thin piezoelectric films are made of oxide based on perovskite lead zirconate titanate,

the degree of (111) crystal orientation of the first thin piezoelectric film is 50 % to 80 % inclusive and

the degree of (111) crystal orientation of the second thin piezoelectric film is 95 % to 100 % inclusive.

42. An angular velocity sensor according to claim 38, wherein

the chemical composition ratio of the layered piezoelectric film is represented as [Pb]:[Zr]:[Ti] = (1+a):b:(1-b),

the first and second thin piezoelectric films have the same value b of 0.40 to 0.60

inclusive,

the first thin piezoelectric film has a larger Pb content than the second thin piezoelectric film,

the first thin piezoelectric film has the value a of 0.05 to 0.15 inclusive and

the second thin piezoelectric film has the value a of 0 to 0.10 inclusive.

43. An angular velocity sensor according to claim 38, wherein

the orientation control film is made of oxide based on perovskite lead lanthanum zirconate titanate and

the degree of (111) crystal orientation of the orientation control film is 50 % or more.

44. An angular velocity sensor according to claim 38, wherein

the chemical composition ratio of the orientation control film is represented as [Pb]:[La]:[Zr]:[Ti] = x × (1-z):z:y:(1-y),

the value x is 1.0 to 1.20 inclusive,

the value y is 0 to 0.20 inclusive and

the value z is more than 0 and not more than 0.30.

45. An angular velocity sensor according to claim 38, wherein

the orientation control film is made of lead lanthanum zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10 mol%.

46. An angular velocity sensor according to claim 38, wherein

the layered piezoelectric film is made of lead zirconate titanate added with at least one of magnesium and manganese in an amount of more than 0 and not more than 10

mol%.

47. An angular velocity sensor according to claim 38, wherein

the first electrode film is made of noble metal of Pt, Ir, Pd or Ru or an alloy containing the noble metal and is an aggregate of columnar grains having an average cross-sectional diameter of 20 nm to 30 nm inclusive.

48. An angular velocity sensor according to claim 38, wherein

the substrate is made of Si.

49. A method for manufacturing a piezoelectric element comprising the steps of:

forming a first electrode film on a substrate by sputtering;

forming an orientation control film made of cubic or tetragonal perovskite oxide on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the orientation control film by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film, wherein

the step of forming the orientation control film includes the step of providing the orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane by the orientation control film.

50. A method for manufacturing an inkjet head comprising the steps of:

forming a first electrode film on a substrate by sputtering;

forming an orientation control film made of cubic or tetragonal perovskite oxide on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the orientation control film by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film;

forming a diaphragm layer on the second electrode film;

bonding a pressure chamber member for providing a pressure chamber to the surface of the diaphragm layer opposite to the second electrode film; and

removing the substrate after the bonding step, wherein

the step of forming the orientation control film includes the step of providing the orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane by the orientation control film.

51. A method for manufacturing an inkjet head comprising the steps of:

forming a diaphragm layer on a pressure chamber substrate for providing a pressure chamber;

forming a first electrode film on the diaphragm layer by sputtering;

forming an orientation control film made of cubic or tetragonal perovskite oxide on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the orientation control film by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film; and

forming a pressure chamber in the pressure chamber substrate; wherein

the step of forming the orientation control film includes the step of providing the orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane by the orientation control film.

52. A method for manufacturing an angular velocity sensor comprising the steps of:

forming a first electrode film on a substrate by sputtering;

forming an orientation control film made of cubic or tetragonal perovskite oxide on the first electrode film by sputtering;

forming a first thin piezoelectric film and a second thin piezoelectric film made of rhombohedral or tetragonal perovskite oxide successively on the orientation control film by sputtering to provide a layered piezoelectric film;

forming a second electrode film on the layered piezoelectric film;

patterning the second electrode film into a drive electrode and a detection electrode;

patterning the layered piezoelectric film, the orientation control film and the first electrode film; and

patterning the substrate to provide a stationary part and a vibrating part, wherein

the step of forming the orientation control film includes the step of providing the orientation control film with preferred orientation along the (111) plane and

the step of forming the layered piezoelectric film includes the step of providing the layered piezoelectric film with preferred orientation along the (111) plane by the orientation control film.